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The Biology and Dispersal of *Mytilicola intestinalis* Steuer

A COPEPOD PARASITE OF MUSSELS

BY

G. C. BOLSTER

Fisheries Experiment Station,
Conway, North Wales

LONDON: HER MAJESTY'S STATIONERY OFFICE
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THE BIOLOGY AND DISPERSAL OF *MYTILICOLA INTESTINALIS* STEUER

A COPEPOD PARASITE OF MUSSELS

INTRODUCTION

tilicola intestinalis Steuer is a copepod, parasitic in the gut of two genera of molluscs. ially classified as a dichelestid (Steuer 1902), it has since been placed in the family Clausiidae onod and Dollfus (1932).

vas first described by Steuer (1902) from *Mytilus galloprovincialis* Lam. found near Trieste. then it has also been found in *Mytilus edulis* (see below) and in *Ostrea edulis* by Baird, r and Cole (1951). The parasite appears to have spread from the Mediterranean to Dutch erman ports and thence to Great Britain and Ireland.

ias been reported in *Mytilus gallprovincialis* Lam. by the following :

1.	Steuer (1902)	Gulf of Trieste
2.	Steuer (1905)	Gravosa, Italy
3.	Cerruti (1932)	Taranto, Italy
4.	Monod and Dollfus (1932)	Marseilles, Martigues, Banyuls sur Mer
5.	Heldt (1950)	South coast of France (Mussels taken to Tunisia)
6.	Korringa and Lambert (1951)	South coast of France

n *Mytilus edulis* by :

1.	Vayssiere (1914)	Mediterranean
2.	Caspers (1939)	Cuxhaven-Wilhelmshaven area
3.	Ellenby (1947)	Blyth, Northumberland
4.	Korringa (1950)	Zandkreek, Netherlands
5.	Cole and Savage (1951)	A single specimen sent in 1937 by Miss L. Beanland to Dr. J. P. Harding from Portsmouth. In the British Museum
6.	Hockley (1951)	South coast of England
7.	Thomas (1952) (private communication)	Gareloch, Argyllshire ; Rosyth, Fifeshire, Scotland

can be seen from the above list, Mytilicola was present in mussels on the east and south s of England in 1951. It had not been found on the west coast. In North Wales the only el bed which had been examined regularly was at Conway (Cole, 1951). Mussels from beds rmarthen Bay and the Menai Straits were examined from time to time, but no Mytilicola ound. Wallasey was the only other place on the west coast from which mussels had been ned. The commercially important beds in Morecambe Bay had not been surveyed for the ite.

le and Savage (1951) had shown that the presence of Mytilicola is associated with a serious ing of condition in infected mussels. Korringa (1950) found that on the Dutch beds in the kreek, Mytilicola increased very rapidly in numbers during April and May. In the warm ns of July and August, mortality was so heavy among the mussels there that the production rketable fish fell to 5 per cent of normal. The possibility of a similar outbreak occurring itain made a quick decision regarding the first line of approach imperative. The two most t needs were to plot the distribution of the parasite and to investigate possible methods of al control. If much time were spent on investigating control before the distribution of the ite was known, results might not be applicable to all areas. Chemical and physical means een tried and found unsuccessful by Korringa (1950 and 1951). On the other hand, if too time were spent on plotting the distribution of Mytilicola in detail wherever mussels were found, a serious outbreak might have occurred before any control measures had been started.

vas decided that the best course would be to make a rapid survey of the important commercial on the west coast which had not so far been examined, and if these were not found to be infected, on to an examination of nearby beds. In this way the nearest potential source of infection be discovered. It would not be sufficient merely to examine the mussel beds adjacent to ain uninfected commercial beds, because infection, it was thought, could be brought in ls attached to the bottoms of ships. For this reason it would also be necessary to examine and harbours.

The present paper is an account of this survey, and a record of observations made both in field—on the west coast and at Blyth, Northumberland—and in the laboratory, which considered to be significant to the problem of control.

METHODS

When sampling a bed, twenty mussels were taken for microscopic examination and as m individuals as time allowed examined macroscopically while walking over the beds. Whe mussel was placed in the collecting tin, for later examination at the laboratory, a number of o mussels from the same clump or level were opened on the spot. On each area examined number was usually between sixty and eighty. It was by this macroscopic examination Mytilicola was first found at Fleetwood. It was intended that mussels taken for microsc examination should fall within a size-range of from 5·50 to 5·99 cm. This would have ten towards a degree of standardization in results between host-size and number of contained parasi and although the first six samples were actually collected with this aim in mind, the idea hac be abandoned. A size-range consciousness was found to interfere with random sampling. many areas a gradation in size was noticed between mussels situated at different tide levels, b on beaches and those attached vertically on piles. Where the distribution of mussels was verti as on the dock walls, jetties and piers, a boat and rake were used for collection below the w level where this was necessary.

Some places from which samples were examined could not be visited personally. For th marked with an asterisk in Table 1 (p. 21), a full explanation of the sampling requirements given to the collectors. From such samples, comprising between 60 and 100 mussels, which sent to Conway, 20 were taken for microscopic examination and the remainder opened examined macroscopically.

Mussels which were to be examined microscopically were placed in an open tin and kept until required. Notes were taken of the date of collection, on the general factors relatin the area where they were collected, and of the date of dissection. When mussels were ope after they had been kept in the collecting tins for some time, Mytilicola, if present, was usu to be seen in or near the rectum.

On one occasion two parasites were found free in the shell cavity after ten days. In order none should be lost from the examination, the samples were nearly always dealt with within days of collection.

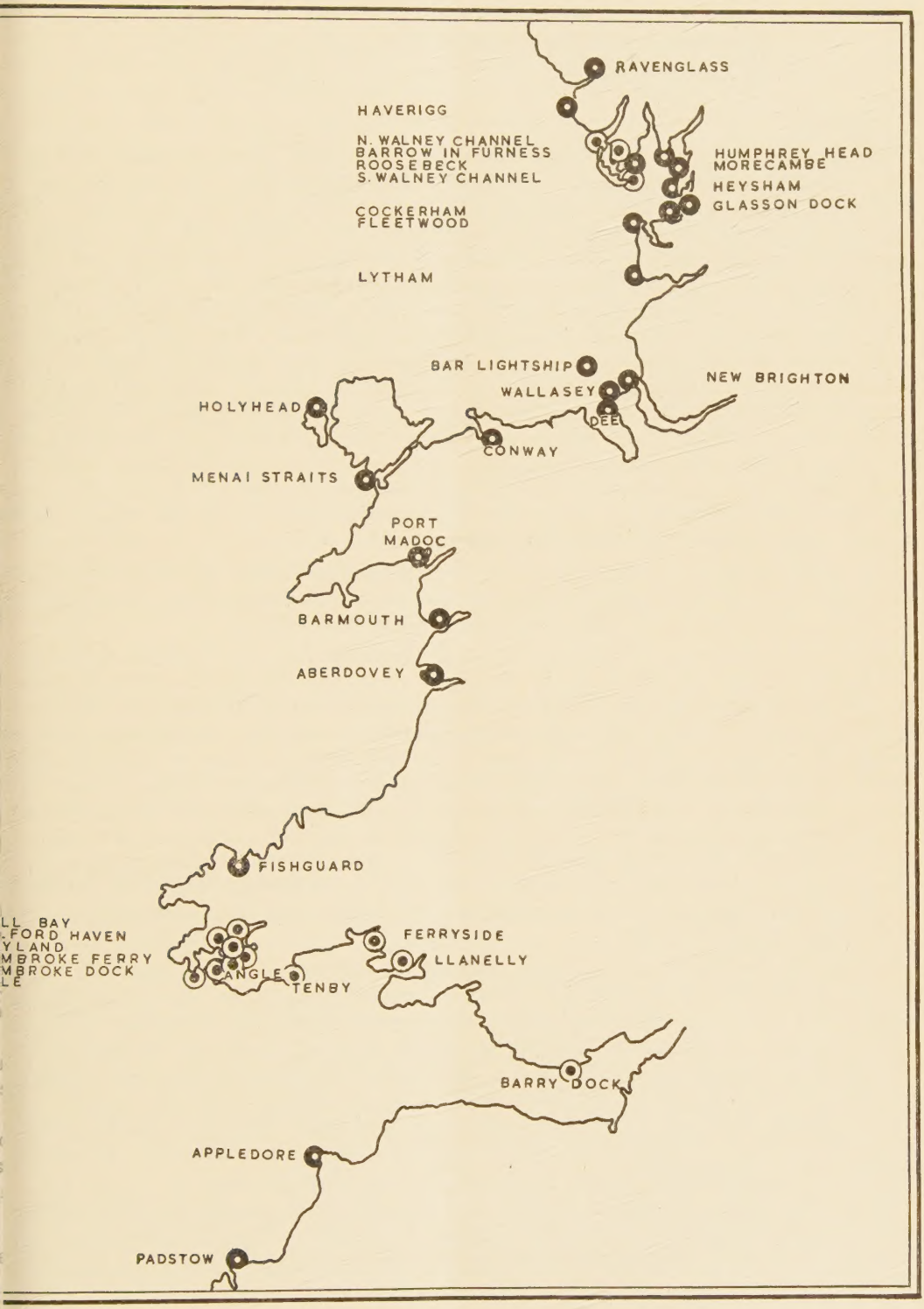
In the macroscopic examination, as much of the gut as possible was uncovered by using a scalpel. This revealed the presence of any adult stages of the parasite. The following proce was adopted for detailed microscopic examination in the laboratory and during the field sur at Fleetwood and Milford Haven. The length of the mussel was first noted, then by the met described in the Appendix (p. 30), the gut was dissected out intact from the point where it j the stomach. It was then placed in a solid watch glass containing sea water. The diges gland, with its contained stomach, was next removed and placed in another watch glass. and digestive gland were then teased out in turn under the dissection lens. Any parasites pre were counted, sexed and sorted under a binocular microscope into two groups—those less t and those greater than 3 mm.—before being stored in Bouin's fluid. They were brought to Con in the fixative and later transferred to 70 per cent alcohol and measured under a binocular mi scope. The sexes were checked again and the number of juveniles, i.e., those less than 3 was noted.

Over a thousand mussels from the west coast were examined in this way. Very many r were opened and examined on the mussel beds.

INFECTION

Factors influencing spread

Infection on the west coast was found mainly in and near shipping ports (Fig. 1, and Tab p. 21) the main centres being at Barrow-in-Furness, Pembroke Dock, Llanelly and Barry D



1. Distribution of *Mytilicola intestinalis* on the West Coast of England and Wales.

◉ Infected Stations

● Uninfected Stations

It may be postulated that there are three possible ways by which Mytilicola infection ca spread :

1. Transportation of infected host on shipping
2. Dispersion of pelagic stages
3. Relaying of infected hosts.

(1) SHIPPING

The parasite was found for the first time during the survey in mussels taken from the bo of a tug which was being scraped on the grid dock in Fleetwood. The tug was from Bar in-Furness, where it was kept constantly afloat and working between the docks. It had scraped thirteen months previously in the same grid dock at Fleetwood. The mussels from tug bottom ranged in size between 2·26 and 4·15 cm. Although four samples were taken various sites within the dock area at Fleetwood, no parasites were found. If mussels which been scraped off vessels placed on this grid previously had been infected, it is almost certain most of them and their contained parasites would have perished. When the grid was swept d at low water, all the mussels were seen to sink into very deep, soft mud. None of the mu growing on the keel supports of the grid was found to be infected. In connection with this of interest to note that this same tug, FURNESS, is the only vessel from Barrow-in-Furness kn to have been scraped at Fleetwood in recent years. Among Mytilicola from this tug, six o thirty-four females carried egg-sacs and eight of the seventy-nine parasites were immature st If nauplii were extruded after the infected mussels had been brushed off the dock, it is improb that they could have made their way to the upper cleaner water at high tide because of the d muddy sediment into which their hosts had sunk.

The same tug makes twelve trips a year from Barrow-in-Furness to Heysham. Althoug parasites were found in samples taken from three sites in Heysham, there is a strong possi of infection occurring there. The same must hold for Fleetwood.

Mytilicola is well established in the docks at Barrow-in-Furness. It is almost certain th was brought to this important ship-breaking port in mussels attached to the bottoms of ve Because of the heavy and widespread infection in mussels within the docks (see Tables 1 a pp. 21, 23), it appears that the parasite has been there for some years. Ex-German ships have laid up there, and in 1947 a floating dock from Lubeck was moored in the Devonshire D As far as is known, Lubeck is free of the parasite but it is possible that the mussels attached t floating dock became paratisized on its journey to this country via the North German p Alternatively, if Mytilicola were already established in the docks at Barrow-in-Furness in there would have been ample time for infection to spread to the mussels covering the flo dock before it was moved to Gareloch on the Clyde in May 1950. Dr. H. J. Thomas, o Scottish Home Department Marine Laboratory in Aberdeen, has since confirmed the presen the parasite in the Gareloch.

Infection in the Pembroke Dock area (Milford Haven) is heavy and widespread. Here a there is a strong probability that infection was brought by shipping. Several ex-German vessels were moored up the River Cleddau, the shoreward prolongation of Milford Haven, a end of the war. In the survey, infection was found to be very heavy on the beach area nea mooring sites for these vessels. (Table 1, p. 21, samples 46 and 48—Mill Bay and Leyland.) places which are infected on the South Wales coast are Tenby, Ferryside, Llanelly and Dock (samples 49 to 52). Cole (1952) points out that vessels laid up in the River Blackw Essex, were towed to South Wales and Barrow-in-Furness to be broken up. In relation t slipper limpet, *Crepidula fornicata* L. and referring to ships, he states :

"There is a distinct possibility of their having sheltered temporarily in Falmouth harbo at the mouth of the Helford river before rounding Land's End. There is no need even to pos a stop at Falmouth, as mussels with limpets attached may have dropped off at any point o voyage."

If these mussels were also carrying Mytilicola—and it is almost certain that they were (m in the Fal and at most places examined along the south coast are infected (Hockley, 1951) spread of Mytilicola was undoubtedly helped in this way.

The same inference relating to the spread of Mytilicola being helped by shipping app Blyth. Dr. H. O. Bull, in a private communication to Dr. Cole, states that he obtained of the slipper limpet, *Crepidula fornicata* L., from Blyth in 1946. These were taken from a G

which, prior to going there, had been laid up in the River Blackwater in Essex. Another , the ss. CAIRO CITY, lay in the Blackwater for four years before it was taken to Blyth to be n up in 1949. Cole (1952) states that while attempting to collect *Crepidula* from her bottom, lay at anchor in the Blackwater, it was noticed that most of the sides of this vessel below ater-line were encrusted with mussels. After she had been moved to Blyth, a sample of g material was taken from her bottom by Dr. H. O. Bull and sent to Conway. "The material ıcluded several chains of *Crepidula*, mostly of two individuals, but with some chains of three. ıussels to which limpets were attached included individuals 65 mm. long which were judged four years old. The largest limpets were 35 mm. long and therefore probably three years (Cole, 1952). On examination, these mussels were found to contain Mytilicola. While it ɔossible to state categorically that Mytilicola was present in the Blackwater before 1946, it ain that it occurred there shortly after that date. It is possible that Mytilicola was brought /th direct from either the German or Dutch centres of infection, but there are records of being taken from the Blackwater to Londonderry (Northern Ireland), Inverkeithing (Fife) ilyth (Northumberland). In addition to ships destined for breaking up, others were moved for refitting and some were sold to firms abroad. There is no evidence to deny the possibility ıe spread of Mytilicola in Britain is similar to, if not directly correlated with, that of *Crepidula*. River Blackwater is considered as a centre from which infection was started, or added to, rts along the west coast.

ELAGIC

tilicola is dispersed within a more limited area by water movements. The free-swimming were observed to live under laboratory conditions at Conway for as long as fifteen days. ger (1951) kept copepodids alive in petri dishes containing filtered sea water for eleven days. ıce of spread by tidal agency is therefore governed by a time factor.

ELAYING

third method of spreading infection is by relaying infected mussels in parasite-free areas. nga, in a private communication, refers to mussels taken from the infected German beds laid in Zeeland waters, as the probable source of infection in Dutch waters. At Newbiggin, ed mussels from Blyth were relaid adjacent to parasite-free mussels from Holy Island. One samples of relaid mussels from Holy Island was later found to be parasitized.

ɔpment of infection in new areas

ɔ localities show evidence from which it can be inferred that the spread of Mytilicola other by human agency is slow. Once infection reaches a new area, the parasite increases in ers and then spreads out to infect hosts within a wider radius. In Barrow it appears to multiplied within the relatively stable and deep, still water of the docks and then spread via ck gates to the outside channel (see Table 2, samples 3, 5 to 10).

he Pembrokeshire area heavy infection is localized around the less enclosed Pembroke dock while Dale, 9 miles, and Angle Bay, 6 miles away, are lightly infected (Table 2, p. 23, samples). In both of these lesser infected areas, the numbers and density of mussels were less than more heavily infected areas. These places are thought to be areas of new or very recent on.

ırt from spatial spread, there may also be a progressive increase in concentration. This e severe. An average of 10 to 12 parasites per mussel has been reached in two samples. stable 1950, G. D. Waugh, private communication ; Ferryside, Carmarthen 1952, with a mussel containing 31 parasites, this survey.) This level of infestation has been accompanied, ıitstable, by reduction in area and density of stock of mussels.

vness of spread is to be expected as reproduction is sexual and takes place internally in the the host (Hockley, 1951). Unless at least one male and one female copepodid (the infective enter the host mussel to become a breeding pair, obviously the parasite cannot become shed as a reproductive unit. Samples 3 and 5, from outside the docks at Barrow-in-Furness, ımples 41 and 42, which were collected away from the main centres of infection in the oke Dock area, all show only one parasite per host (Table 2, p. 23). In these places mussels

were not as numerous as they were in areas showing heavy parasite numbers and 100 per infection. Korringa and Lambert (1951) observe that the number of mussels per volume of w is a factor limiting the degree of infection. This may account for the difference in degre infection between the densely-populated Dutch beds and the less dense beds on the Fr Mediterranean coast.

The possibility of any copepodid finding a host varies directly with the density of the mu in a given habitat. On a thinly-populated mussel bed the chance of a parasite finding a ho small. It is obvious that on a densely populated bed the chance of any one copepodid findi host is greater. Infection in any habitat is governed by the following conditions :

1. At least one copepodid of each sex must enter the same host.
2. Because of a time limit imposed on the parasite by the period of its reproductive poten male and female copepodids must find the host within a period which allows of t developing to sexual maturity together in the mussel. The life span of the adult par is not known.

The chances of these conditions being fulfilled are relative to the following consideration host density and copepodid numbers :

1. A given number of copepodids will have less chance of establishing breeding units w the density of hosts is great.
2. Conversely, where host density is less, provided that the mussels are not too far a the chance of establishment is greater.

This, of course, assumes ideal environmental conditions for all habitats. In the field, how factors which affect the density of the hosts will also be directly related to the colonizing effic of the parasite. There is no doubt that water movement, as a single factor alone, plays a n part in controlling the rate of establishment of new infections in a locality. Once a numb breeding pairs have been established, the rate of infection will be faster when the host concentrated, giving free-swimming copepodids a greater chance of entering mussels b the pelagic stage is terminated. There is in fact a reversal in the effect of host density o parasite, and infection may proceed as a geometrical progression. Korringa (1950) found in the Zeeland waters Mytilicola reached sexual maturity in seven weeks. The number of produced by one female is in the order of from two to three hundred in the two egg-sacs. considerations offer some explanation for the observations of Caspers (1939), Ellenby (1 Korringa (1950) and Hockley (1951), all of whom remarked on the "sudden" appearance c parasite.

Marine and estuarine environments

Caspers (1939) and Ellenby (1947) have remarked on the parasite being found in estu areas. Grainger (1951) found that of six infected areas in Ireland, four were estuarine. I present survey, Mytilicola has been found in estuarine environments at Ferryside and Lla and from open marine environments in the North and South Walney Channels (Barrow-in-Fr area), and at Angle, Dale and Tenby (Pembroke area). The other places on the west coast it is found are ports, i.e., Barrow-in-Furness, Fleetwood and Barry. Mytilicola was not at Heysham, Liverpool, the Dee estuary, the North Wales beds or at Fishguard. At Hey and Fishguard mussels were abundant only outside the dock area in open marine environ In the Mersey and Dee estuaries mussels were rather scarce—a condition attributed loca oil pollution and sanding-up respectively. Padstow and Appledore, two places on the no coastline of Cornwall and Devon where large beds of mussels are found, were also free. estuaries cannot accommodate ships of deep draught, and this may account for the abse the parasite.

These findings are in general agreement with Hockley (1951), who found that Mytilico become established equally well in both types of habitat on the south coast of Englan

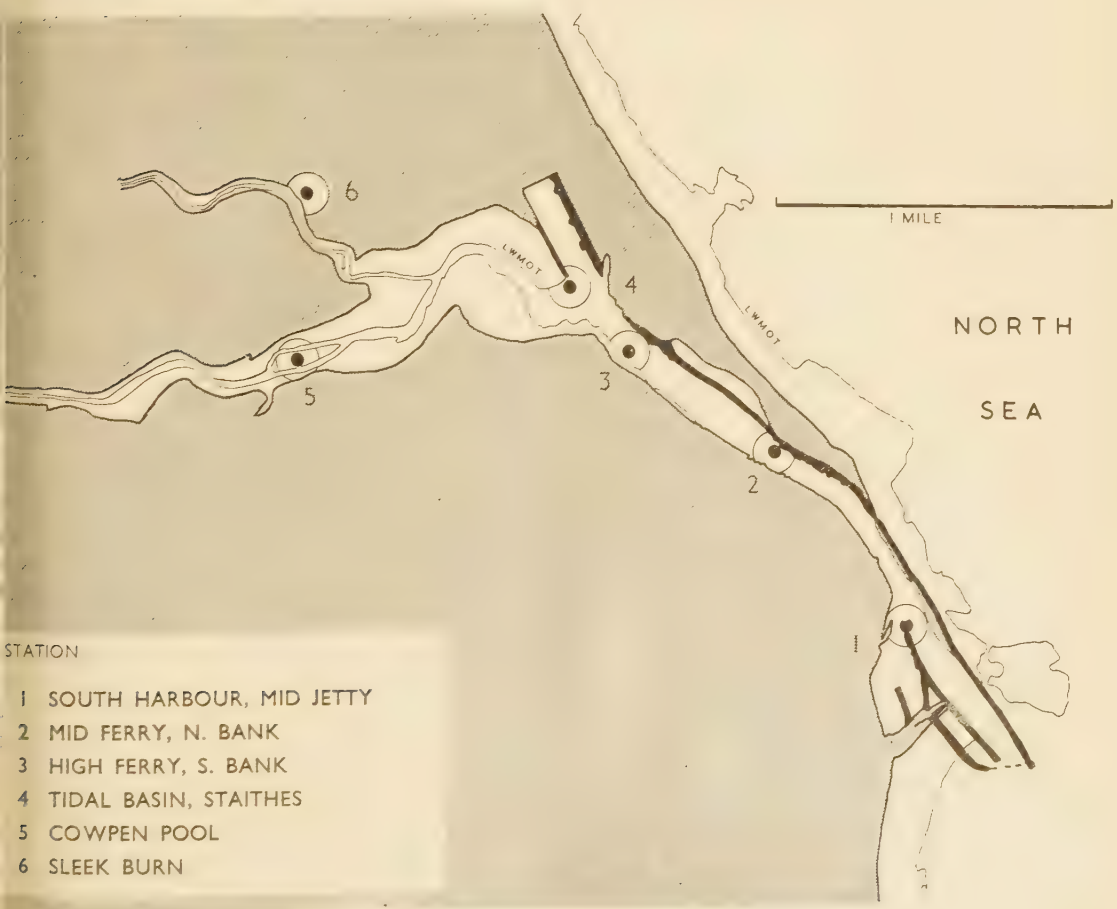
From observations made during this survey, it is considered that where Mytilicola is p in estuarine and open marine environments, it has generally spread to them from nearby Where mussels are plentiful both inside and outside harbours, e.g., Barrow-in-Furnes Pembroke docks, the spread is fairly rapid. Because, as will be shown later (p. 1

num salinity level for the development of Mytilicola is rather below that of the open sea, to be expected that Mytilicola will become established in greater numbers and more quickly ıe less saline waters of docks and estuaries. This has in fact been found during the survey at Blyth. Hockley (1951), referring to the south coast of England, has pointed out that "in of the power of rapid colonization, it seems likely that those few estuaries that remain free not for long maintain their immunity." It is important to emphasize that the infective stages Mytilicola are extremely hardy and that where once they became established in a marine ronment the increased salinity will not necessarily prevent spread. The seriousness of these rtions in relation to the commercially important mussel beds, both estuarine and marine at way, Morecambe Bay and the Wash, cannot be over-emphasized.

nsity of infection in relation to current and exposure

ɔme observations on distribution in relation to current speed were made at Neyland in the ıbroke area. The samples comprised mussels collected from two habitats in this place. Eight sels were taken from a small, densely populated bed situated under the ferry slips. There a rapid flow of water over this bed at each tide. Twelve were taken from the nearby beach. se from under the ferry slips contained 15 parasites (8 hosts), while those from the beach :ained 72 parasites (12 hosts).

. second observation made at Tenby was that there was a varying degree of infection with th. The sample was divided into four groups each of 5 mussels. These were taken from · height levels on a rock.



2. Map of Blyth Estuary, Northumberland, showing position of Stations.

Height above sand in feet	*No. of parasites in five mussels*
5	6
4	14
3	21
1	27

Although it is considered certain that flow of current must govern the possibility of a copep entering a mussel (Hockley, 1951, Meyer and Mann, 1951), it was decided to test the hypot of varying degrees of infection with depth in relatively sheltered water. Blyth was chosen suitable place to do this. The Blyth estuary was divided into six sections, with a station in (Fig. 2), from which mussels were taken in samples of 20 at varying height levels. The dist between highest and lowest mussels varied considerably at the different stations. At Stati it was 10 feet ; at Stations 1 and 3, 6 feet ; Station 6, 4 feet ; Station 5, 3 feet ; and at Stati only 2 feet, which did not allow of a sample being taken for this purpose. At Station 1, two s were taken, one comprising four samples and the other two. At Stations 1, 3 and 4 (Tab p. 26) there was a significant difference in the degree of infection with depth. At all of these sta mussels were taken from the piles under jetties. At Stations 5 and 6 (samples 76, 77, 78 and the height differences were not great ; the mussels were taken from horizontal positions on where the action of the tides would have tended towards a more even distribution of the infe stages.

Hockley (1951) has suggested that "because of the sinking effect in the infective copepodid s mussels on the bottom are much more susceptible to infection than those raised on steep surfa Korringa and Lambert (1951) found that in areas examined on the French Mediterranean c infection was lighter in mussels nearest the surface. Meyer and Mann (1951) state that, their observations, it appears that in the Wattenmeer the parasites were more numerous w the mussels were in deep, still water. Parasites were absent or occurred only in small num where the current was strong. They found that while isolated mussels situated high up on r were free, those in deep crevices between piles were heavily infected. They add that "rese on mussels which are situated in deep water has not been carried out yet".

Varied infection with depth is not considered to be the result of any single factor. Obvi mussels on the lower range of their distribution are covered by the tides for longer period those which are higher placed. This is the most probable reason, but the environmental cond of speed of current, light, salinity and temperature will exert a modifying effect. It has observed (above) that the degree of infection increases with depth more markedly where mu are found growing on piles.

BIOLOGY—NOTES AND OBSERVATIONS

Influence of light on dispersal of planktonic stages

Steuer (1905), Pesta (1907), Caspers (1939) and Meyer and Mann (1951) found a positive ph tropic response in the nauplius and metanauplius, and a negative one in the infective copep stage. Grainger (1951) found that the nauplius is positively phototropic and very active. metanauplius is less active and has a weaker phototropic response. The copepodid he fou be an active swimmer but notices that "individuals differ considerably in their response to l some have positive, some a negative, and some scarcely any response to ordinary daylight". noted by Hockley (1951), it was observed in the laboratory at Conway that while both nau and metanauplius were photopositive in their response to daylight, the copepodids differ behaviour from these two stages and were usually seen swimming at the bottom of the be in which they had been reared. This appears to be an important factor governing distribu

We have seen that infection is generally found to be heavier in mussels taken from the d parts of a habitat. It is submitted that a partial explanation for this phenomenon is to be f in the following. The first two free-living or planktonic stages—nauplius and metanaupl are photo-positive to daylight. Although there is no evidence that these migrate vertica nature, it does appear that, if the observations made in the laboratory apply equally in the there will be a tendency for nauplius and metanauplius to swim towards the surface. The of Hardy and Gunther (1935) on the dynamics of water currents has shown that dispers

nkton is accelerated over a greater area on the surface than in lower water levels. If this holds the smaller water masses significant in the present problem, it would make for a generally wide persal of the first two larval stages of Mytilicola in the time taken by them to reach the copepodid ge ; that is, about 36 to 48 hours at a laboratory temperature of 18°C. It is thought that ause of the observed positive geotropism and the weak positive phototropism of the copepodid, re would be a tendency for this stage to sink to the bottom in nature. In the laboratory, the epodid has lived for as long as 15 days. It is doubtful that a period as long as this would vail in the field. If the copepodid sank on to a densely populated mussel bed the chances a host being found quickly would be good. If on sinking to the bottom, the copepodid were sented with a set of adverse environmental conditions, such as turbulence or heavy sedimentation, chances of survival could be lessened. Nothing is known concerning predators of the planktonic ges of Mytilicola.

eding and development in relation to season and water temperature

The intensity of breeding at different seasons may be determined by noting the proportion of ge females carrying egg-sacs and relating it to the number of juveniles in a sample.

Korringa (1951) found in the Netherlands that breeding began early in March and reached height in June and July. Meyer and Mann (1951) record a maximum percentage of females h egg-sacs in August 1950 in the German Wattenmeer, declining to nil towards the end of uary 1951. No breeding females were present in February and March 1951. The statement the same publication that "le pourcentage des femelles porteuses d'ouefs est très élevé pendant mois de janvier à octobre . . . mais vers fin octobre leur nombre diminue, et vers janvier 1951 en rencontre peu or plus du tout" is not in good agreement with the table of percentages to ich it refers and suggests that the first reference to "janvier" may be a misprint.

Grainger (1951), on the other hand, examining mussels from near Cork, Ireland, concluded t "females carrying egg-sacs were found throughout the year, but more carried them in summer". s lowest percentage of females bearing egg-sacs occurred in January (44·4 per cent) and his highest ·3 per cent) in July. These figures were obtained by dividing the number of females bearing g-sacs (× 100) by the total number of females, including those too small to breed. A more iable picture of breeding intensity is obtained by substituting "total females 5 mm. or more in gth" for "total females" in this calculation, since the presence of a large proportion of immature nales may result in an apparent low breeding intensity and the smallest females bearing egg-sacs asure 5·0 mm. Grainger (1951) further states that immature stages "were present in highest mbers in November and December. None was found in June and July and very few in May d August". This scarcity of juveniles during the summer when, as noted above, the percentage the total females carrying egg-sacs was at its highest suggests that egg-sacs may have been ained throughout the summer without hatching. However, it is usually considered that the gs of copepods are fertilized before the egg-sacs are extruded, and it has been found that hatching ually occurs within eight days at summer temperatures in egg-sacs removed from the parent nale.

t is possible that Grainger's material included a proportion of unfertilized females, since the rage number of female Mytilicola per host in his material never exceeded three and was, during summer, about half that density. This suggests the occurrence of a substantial number of ssels carrying only one or two parasites. In these circumstances a proportion of the females uld be unable to breed. Several instances were noted during our investigations of single females ring egg-sacs in mussels which contained no other parasites. Unfortunately it was not deter-ned whether these egg-sacs contained developing nauplii. There is the possibility, however, t the males may not survive for long after fertilization has taken place.

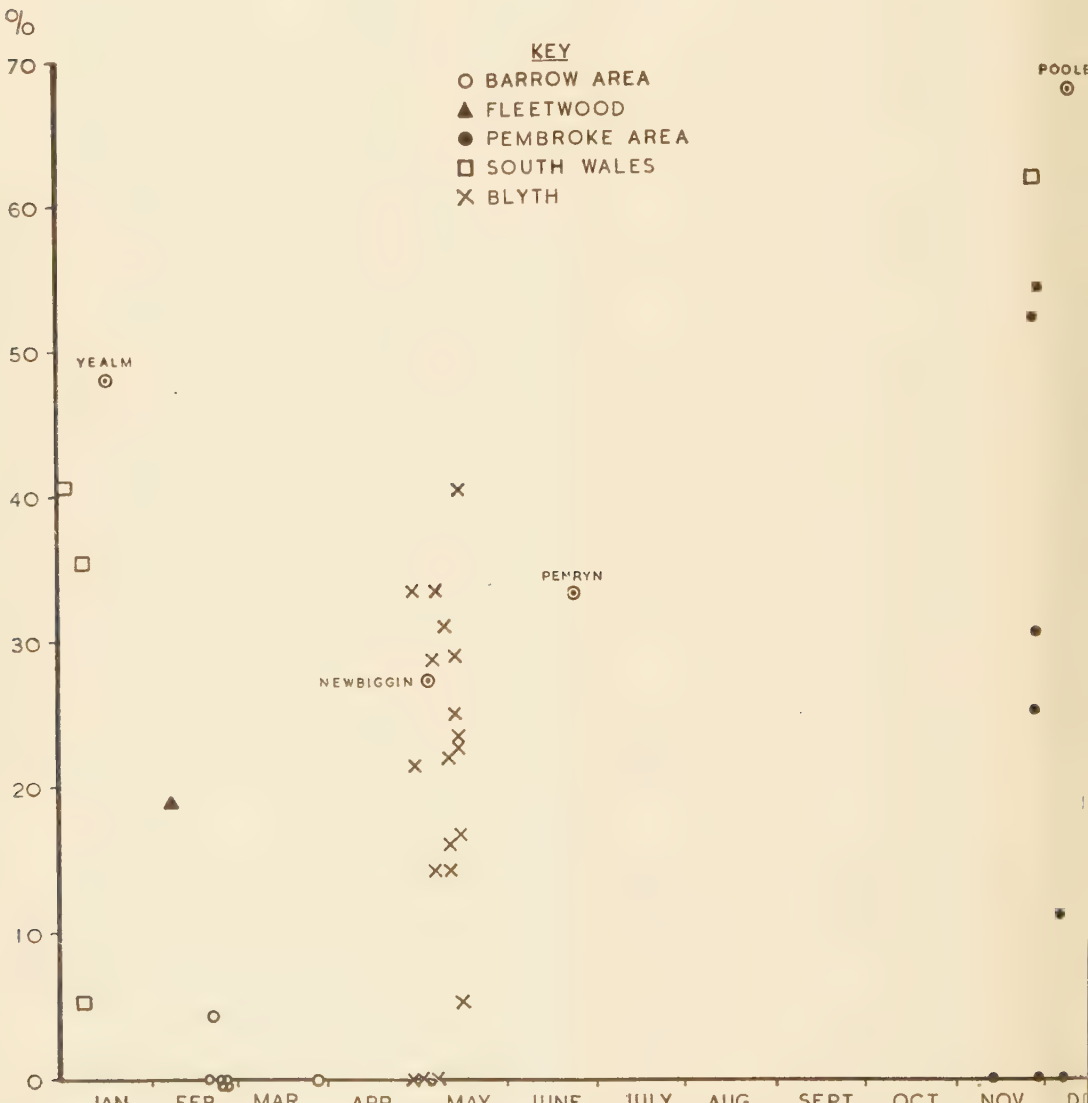
mmature stages have been found during the present investigations in the stomach and the erticula of the digestive gland. Grainger (1951) does not record having found parasites in se parts of the host, nor did he observe any copepodid stages in the mussel, so that it is possible t juveniles may have been overlooked.

Hockley (1951) states that he has examined mussels from the neighbourhood of Southampton t all times of the years 1948-50, and no significant seasonal variation (in the intensity of breeding) s detected. Males were always the more numerous, a typical sample yielding 182 males, females. Larval stages were seldom found. Although some may have been overlooked

because of their small size, I believe it safe to infer that the time occupied by the three lar parasitic instars is short when compared with the average span of adult life".

Cole and Savage (1951), reporting upon material received in January from Blyth, Northumb land, found abundant juvenile Mytilicola in the hosts—up to 45 per mussel.

In the samples of mussels examined during the course of this investigation the proportion adult females bearing egg-sacs varied from 67·6 (Poole, Dec.) to nil (Fig. 3). Other samples fr infected beds on the east coast of England examined at the Ministry's Burnham-on-Cro Fisheries Laboratory by Mr. G. D. Waugh gave similar results. Mussels from Whitstable, Ke collected in July 1950 gave 82 per cent of adult females carrying eggs, while two samples collec from Southend-on-Sea and Leigh-on-Sea, Essex, in February 1950, gave corresponding figu of 0·0 per cent.



3. Percentage of female parasites carrying egg-sacs in relation to season of the year. No samples were collected during the summer months.

From these superficially conflicting statements there emerges a definite pattern in relatic the breeding of Mytilicola and water temperature. On the east coast of England, bree continues in most places until December and January but ceases in February and March begins again in April. On the Channel coasts of England and Ireland breeding occurs throug

year. If we examine the records of sea temperature in these areas (*Atlas de temperature et inité* : International Council for the Exploration of the Sea, 1933), we find that off Newcastle mean temperatures for January, February, March and April are 6·5, 5·7, 5·5, and 6·4°C. respectly. Off Southampton the corresponding temperatures are 8·0, 7·25, 7·0, and 8·0°C. Off Cork y are slightly higher still (Proudman, Lewis and Dennis, 1937). It seems, therefore, that about C. is the critical temperature for the breeding of Mytilicola, and in areas where the temperature es not fall so low in normal years breeding may occur throughout the year. The continuous eding area will include the whole of the south and west coasts of England and Wales, south of glesey. Off the German and Dutch coasts sea temperatures are usually about 1°C. lower n off the east coast of England, and the non-breeding period will normally cover the first three nths of the year.

Turning to the size at maturity, there are indications that this is not the same at all localities. ouping the samples from Pembroke and South Wales (Table 3, p. 24), the mean lengths for eeding females are 8·06 and 7·49 mm. respectively.

At Blyth the mean lengths of breeding females at Stations 1 to 5 were 8·17, 8·20, 8·14, 8·54 and 48 respectively (Table 7, p. 28). At Station 6, where fresh water influence was most evident, there is a slight but definite dwarfing effect, breeding females averaging 7·58 mm. only. Many olluscs extending into brackish water show a similar diminution in size at maturity.

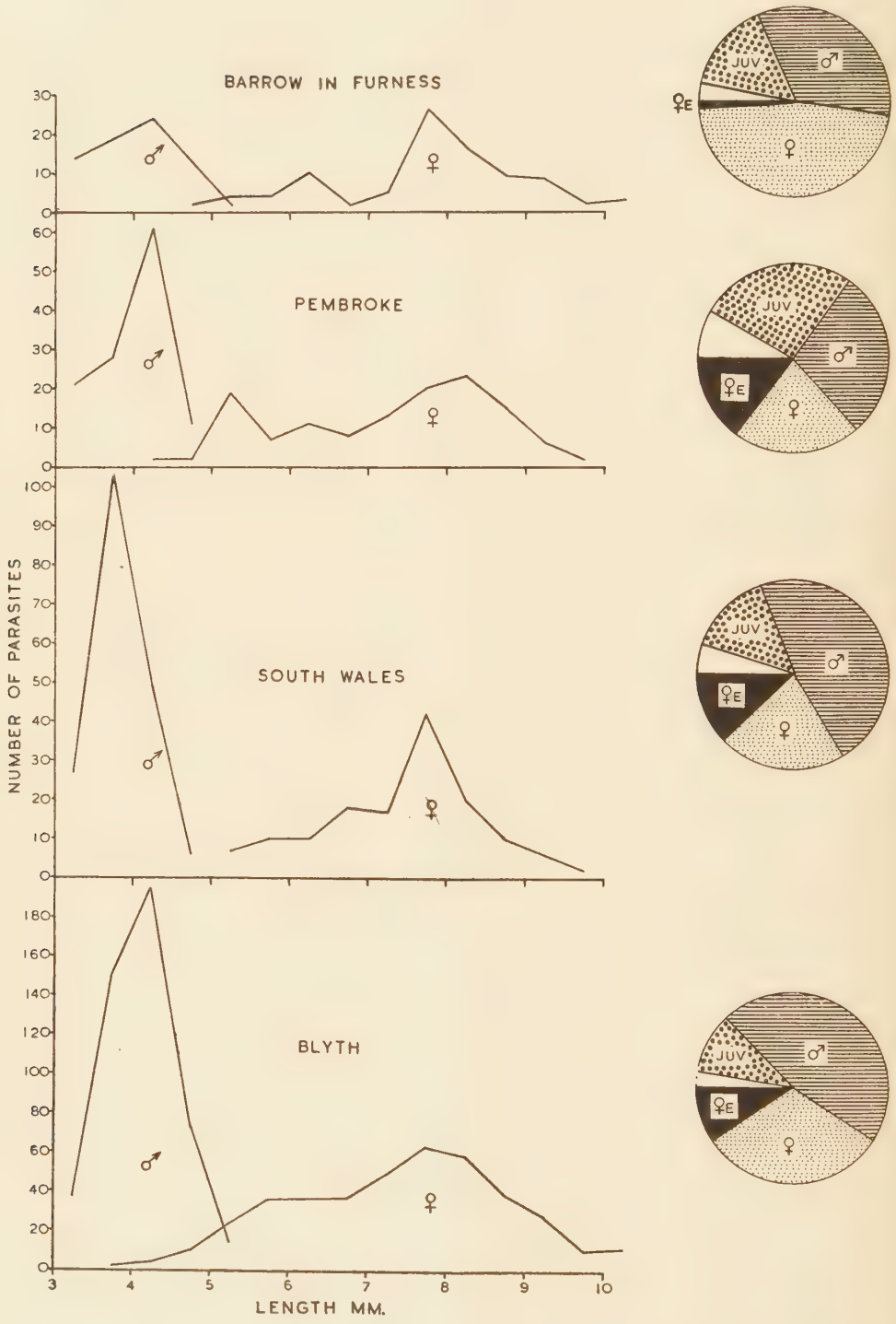
On the south coast, at Poole and R. Yealm (Table 3), breeding females were larger than in South ales, with average lengths of 8·75 and 8·30 mm. respectively. At Barrow only one female rrying eggs was obtained. In the samples as a whole the largest breeding female measured ·5 mm. and the smallest 5·0 mm.

Fig. 4 gives the size distribution of parasites over 3 mm. in length from Barrow-in-Furness, mbroke, South Wales and Blyth. It will be seen that males and females overlap to a very small tent (*cf.* Cole and Savage, 1951, Fig. 3), and this suggests that the growth-rate of the female rasites greatly exceeds that of the males. Very few males exceed 5 mm., and if the population divided at this length, the sexes are separated with but few exceptions. The size distribution the females indicates a succession of broods produced at intervals throughout the breeding ason—a conclusion supported by other observations.

Mytilicola has been observed to develop from the egg to the copepodid in temperatures ranging om 6° to 19°C. *Mytilus edulis* grows well in cool waters and does not thrive in water of a mperature over 20°C. Mytilicola, however, as Korringa (1951) has observed, does become ore active when water temperatures increase in June and July. He found that a high percentage larval Mytilicola thrived in their pelagic state at higher temperatures, and he associates with is increase in temperature a falling-off in condition of the mussels in the warm months, and n increase in the activity of Mytilicola. This enabled him to forecast that in 1950 the critical me for mussels in Dutch waters would be sometime between mid-July and the end of September, e period of maximum water temperatures.

The temperatures of coastal waters around Britain vary between 0° and 25°C. Temperatures ithin the upper range of this scale have proved suitable for hatching and development of the rasite under controlled conditions. Grainger (1951) has reared copepodids in the laboratory a temperature of from 13° to 14°C. A temperature of 18°C was used for hatching by Hockley 951), and at Conway this higher temperature was found to be very successful—nauplii hatched from 2 to 10 days in beakers of unaerated filtered sea water (salinity 29·0 to 31·4‰).

Grainger has suggested that lower temperatures retard both the hatching of the eggs and the evelopment of the larvae up to the infective stage. He suggests that "It is not unlikely that e eggs laid in the autumn are carried throughout the winter and develop very slowly because f the lower temperatures. When the temperature rises in the summer the eggs may hatch to roduce larvae which enter the mussels in numbers in the autumn." This appears contrary the seasonal pattern of breeding shown above. Grainger's theory might account for the low umbers of females with egg-sacs found in Barrow-in-Furness in February and March, 1951, but e percentage of immatures found in this area at this time (15·19) suggests that there had been me breeding shortly before this date. It is impossible to offer any reasonable explanation of e seasonal absence of juveniles from Grainger's samples.



4. Size-distribution and composition of the populations of *Mytilicola intestinalis* found in mussels from infected areas on the West Coasts of England and Wales. The plain segments in the circles comprise the parasites damaged during dissection of the host-mussels and therefore not sexed.

opepodids were immobilized when kept in water at 0°C. for four days at Conway. When temperature of the water was raised to 18·5° C., many of the copepodids recovered and were essfully used to infect mussels in water at room temperature (*ca.* 14°C.).

he higher temperatures in the summer are correlated with greater activity on the part of the podids. If larvae hatch in the summer it is most unlikely that they will remain in the free-nming stages for 8 to 12 weeks to enter mussels in the autumn. If they do, in fact, then it be expected that Grainger would have found large numbers of juveniles in the summer. This not the case. Copepodids have not been kept alive in the laboratory for longer than fifteen unless they enter a host. Because of the passive method of infection, there is no known on why the copepodids should not enter their hosts during the summer months unless it be the feeding of mussels was considerably retarded. This, however, cannot hold. In fact the rse is true—mussel feeding activity is greatly increased after the spawning period finishes in June.

ience of salinity

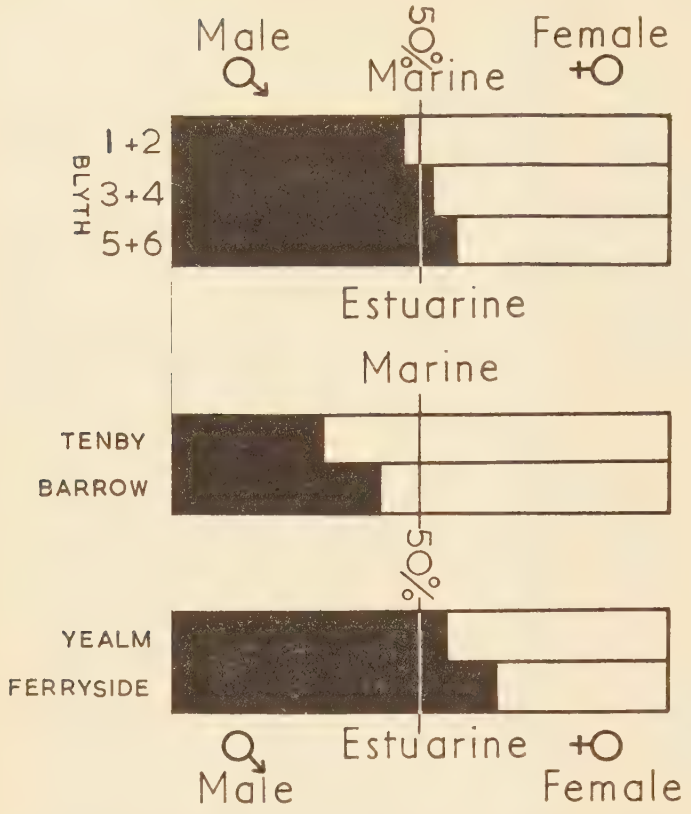
orringa (1951) states that it is not likely that either temperature or salinity limits infection, use there is plenty of variation in these in infected areas. In 1950, the year of catastrophic sel losses on the Dutch beds, the changes in temperature and salinity had not been noticed. nity is thought to have been about 28‰. On lowering the salinity in a large tank containing sels to as little as 10‰, Korringa found that the mussels died, but not Mytilicola, which proved e more euryhaline than their hosts.

leyer and Mann, reported by Leloup in Korringa (1951), have shown that the minimum salinity which Mytilicola can survive is about 5‰. In the laboratory at Conway copepodids have reared successfully at a temperature of 18°C. in waters of salinity 17·2, 18·5, 23·0 and 30·8‰. ssels placed in dishes containing sea water of salinity, 20·5 and 31·4‰ have been infected, showing average density per host of 2·37 and 4·70 parasites respectively. The suggestion that infection urs less readily at much reduced salinity was confirmed by the analysis of observations made Blyth (Table 8, p. 29). These observations also show that infection is less near the mouth of the uary, where salinity is rarely reduced below that of the sea outside, than in the middle section he estuary, where moderate fresh water influence is discernible.

able 8 shows that the percentage infection was least at Blyth at Station 1 (Fig. 2), where it was e more than half that observed at Station 4 up-river. The average number of parasites was least in the most marine habitat near the mouth of the estuary (21·62 parasites per 20 mussels Station 1 ; 96·50 per 20 mussels at station 4). The range in salinity observed in April at tion 1 during a tidal cycle was from 32·7 to 33·6‰, whereas at Station 4 it was 30·79 to 32·16‰. s not suggested that salinity alone was responsible for the differences observed, as the degree xposure and the speed of the current also varied. It has already been shown that these influence ction. It is probable, however, that a small admixture of fresh water results in optimum ditions for the survival and development of the parasite.

here was a slightly lower percentage infection and a markedly smaller number of parasites host in the Sleek Burn (Station 6, Fig. 2), the station most affected by fresh water discharge. this station salinity was observed to range from 5·63‰ at low water to 32·52‰ at high water. Station 5 (Cowpen Pool) the mussels examined were taken from the bank, well clear of the water stream, and the observed salinity range to which they were exposed during a tidal cycle 30·0 to 32·52‰, i.e., markedly less than at Station 6. It seems, therefore, that frequent osure to water of low salinity may limit infection. Further investigation is clearly needed in uaries where mussels are present below low water mark (this was not the case at Blyth) over ide range of salinity conditions. There is also need for extended work in the laboratory to ermine the extent to which infection occurs in mussels maintained constantly at salinities near limit of their toleration. It is also desirable to investigate the changes in parasite content ch result when infected mussels are moved from a marine to a fully estuarine environment vice versa.

here is evidence from Tables 2 and 6 (pp. 23, 27) to suggest that salinity may affect the sex ratio he parasites. In the lower part of the Blyth estuary (Stations 1 and 2), where the salinity is very e reduced from that of open sea water, female Mytilicola were slightly more prevalent than les (91 ♂♂ : 106 ♀♀). At Stations 3 and 4 in mid-estuary, the two sexes were very nearly equal umbers (255 ♂♂ : 233 ♀♀). The same tendency is evident to some extent in Table 2. Ferryside



5. The influence of salinity upon sex-ratio. Percentages of male and female Mytilicola in the different sections of the Blyth Estuary (numbering of station from mouth to headwaters) and at representative marine and estuarine stations.

and the River Yealm, b estuarine stations, show prevalence of males, while Tenby and Barrow, b marine habitats, the fem are far more numerous (Fig Possibly some other fa such as exposure also fluences the survival of n and female parasites ; perh also males may not long vive after effecting fertilizat The latter hypothesis rece some support from the rela scarcity of males at Barrov late winter when the breec season had practically en It is possibly significant the two samples from P broke Ferry and Mill which include a high per tage of juveniles—showing breeding was in full swi also show an almost e number of males and fem In this part of Milford H the conditions are marine sheltered. None of the ples for Pembroke was t from a habitat substant influenced by fresh w discharge.

Effect on host

Cole and Savage (1951) concluded from their study of Blyth mussels that "the presenc Mytilicola is associated with a serious reduction of condition in infested mussels". Kor (1951) points out that a preliminary survey of mussel beds in the Zandkreek area showed a of condition in mussels where infection was in the order of 5 to 10 Mytilicola per host. This of condition was not apparent where the occurrence of the parasite was light (1 to 3 per mus During the present survey it has been observed that the presence of the parasite is usually associ with poor condition in the host. In the Pembroke area the condition of mussels, whether infe or not, was poor, while in the sample from Llanelly (sample 51) the general condition was n as "good", even in a host containing 19 adult parasites.

Although the study of condition in relation to parasite content of mussels was outside the s of this survey, the impression gained is that the sample from Llanelly was an exception. possible that in some areas, through the agency of some unknown set of conditions, infec though heavy, may not be apparent in its effect on the condition of the host. This is sugg only as a possible secondary explanation for infection escaping detection until it has bec widespread and heavy. Infected mussels may hold their condition more easily if the degre infection is increased at a time when the gonads of the host are developing or have develc Korringa (1950) remarks that infected mussels are unable to breed. Fecundity is cert diminished in infected mussels. This probably results from a diversion of products whic normally used in the development of the gonads to a form of compensatory metabolism in the

Meyer and Mann (1951) have shown that the filtering capacity is reduced in infected mu in proportion to the degree of infection ; that the absorption of albumen is more rapid and their respiration rate is twice that of healthy mussels. They found that although the host c if it was fully developed, live with little difficulty while containing three parasites, the very y

PLATE I. View across the mussel beds at Whitstable, showing in the foreground great reduction in population of mussels as the result of very heavy attack by Mytilicola. *Photo :* D. Key.

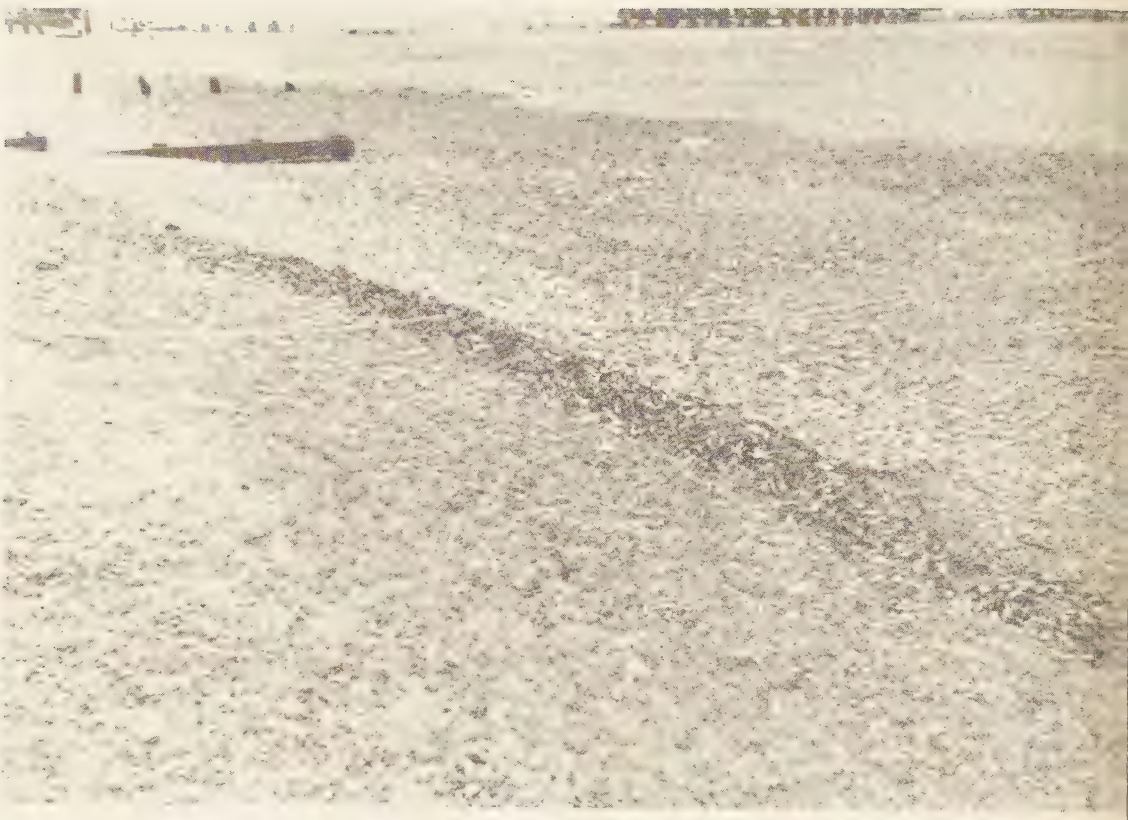


PLATE II. Shells of recently dead mussels forming windrow at high water at Whitstable following devastation of beds by Mytilicola. *Photo :* Dr. G. E. Newell.

igh lightly infected mussels showed a high mortality. In the mussels from Blyth examined Cole and Savage (1951) the minimum infection causing serious loss of condition seemed to ather higher.

n the German Wattenmeer, Meyer and Mann (1951) found that infection occurred in "young" ssels during the breeding season as much as in mussels which had finished breeding. Korringa Lambert (1951) found a 30 per cent infection of 1 or 2 parasites per host in mussels between nd 35 mm., growing on a pile in a mussel bed near Mèze on the south coast of France. Cole Savage (1951) found an average of 14·25 parasites in mussels between 3·5 and 4·99 cm. ected at Blyth in January.

n sample 70 (Table 5), which was taken from the uppermost mussels at Station 3 in the Blyth ary in May, the ten smallest, ranging in size between 3·48 and 4·28 cm., with an average length 3·87 cm., contained in all 28 parasites. The other ten mussels of this sample, ranging in size ween 4·46 and 5·66 cm., with an average length of 5·23 cm., contained 24 parasites. In sample 9, rrow-in-Furness), the ten smallest mussels, ranging in size between 3·57 and 3·83 cm., with average length of 3·68 cm., contained 15 parasites. The ten largest mussels, ranging between 4 and 5·89 cm., with an average length of 4·29 cm., contained 16 parasites. At Newbiggin ble 5, sample 80) the smallest infected mussel was 3·34 cm. long and contained 14 parasites, largest was 6·79 cm. and contained 10 parasites. The two samples from Blyth and Barrow the only ones in which the difference in the size of hosts allows of such comparisons. In most he other samples the difference in size was less. Grainger (1951) found that the smaller mussels tained few copepods, but he does not record having found immature parasites in the digestive nd, and some may have been overlooked ; nor was consideration given to the fact that the wth-rate of young mussels is retarded by infection. There is no definite evidence from this vey to show that smaller mussels in any one habitat are less heavily infected than larger mussels.

The parasite enters by the current of water made by the mussel. This is confirmed by observa- ns made during infection experiments at Conway. Because of this passive method of infection, er conditions being equal, the intake of parasites will be proportionate to the filtering efficiency the host. Jørgensen (1949) has shown that filtering efficiency may vary in small *Mytilus edulis*. experiments where suspensions of flagellates and Nitzschia were used, he found feeding rates water transport) of 80, 32 and 40 ml. per hr. per mg. N in mussels of average lengths 1·5, 2·9 1 3·2 cm. respectively. "The feeding rates are shown to be comparatively larger in the smaller mals than in the bigger ones." Fox, Sverdrup and Cunningham (1937), on the other hand, e shown that in *Mytilus californianus* there is an appreciable increase in filtration rate with rease in size of mussel. Mussels of average size 74, 102 and 178 mm. gave filtering rates of to 2·1, 2·2 to 2·9, and 1·8 to 18·1 litres per hour respectively. Although the filtration rate small mussels per unit of flesh weight may be greater than that of large mussels, the absolute ume of water passing through the gills will almost certainly be less. It may well be, however, t the young mussels may filter more at a time when the larger mature mussels are in the process spawning—a time when food intake is considerably reduced.

t has been noticed that young mussels often settle on the older, already existing, stock on a d. It is possible that this position may be more favourable for the intake of parasites.

Though at first there is no visible difference between free and infected mussels on external mination, severely infected mussels are later seen to break away from the byssal attachments d die. Plates I and II show the result of severe infection at Whitstable in July 1950. These ssel beds have now been almost totally destroyed. A sample of mussels from this area, eived at Conway in October 1949, included one containing no less than 57 adult parasites. internal examination, there is a marked change in the appearance and volume of flesh in heavily ected mussels. The digestive gland, which is dark brown in healthy mussels, turns to an ochre our and, in dying mussels, to yellow or cream. The appearance of the mussel bed changes dually as the mortality increases. At first, empty and gaping valves are to be seen ; later, en the byssal attachments disintegrate and the empty valves are washed away by the tides, ked patches appear. These bare patches may be scoured clean or sanded-up, depending upon swiftness of the currents ; successful recolonization of denuded areas has not so far been served. The surviving mussels at Whitstable are still heavily infected with Mytilicola.

Dollfus (1951) is not convinced that infestation with Mytilicola results in the death of mussels. considers that the epidemic mortality in the Netherlands must have been due to another cause—

a bacterium or virus ; and that mussels infected with Mytilicola may be weakened and thus beco more susceptible to the disease. Such a contention is very difficult to prove or disprove. T basic fact with which the mussel farmer has to contend is that heavily infected mussels are th and weak and are liable to die in quantity when environmental conditions become unfavourab e.g., during very hot summers.

Cross-infection of oysters and mussels

Mytilicola was found in *Ostrea edulis* in the Penryn and Blackwater rivers, in Cornwall a Essex respectively, by Baird, Bolster and Cole (1951). Copepodids hatched from egg-sacs remov from a parasite found in one of these oysters were used successfully to infect four Conway musse The mussels were kept in water of salinity 31·8‰ at temperatures from 13° to 15° C. and dissect six weeks after the copepodids had been introduced ; 23 parasites were found, an average of 5 per host. Experiments were also made to determine whether there was any difference betwe the susceptibility of mussels and oysters to infection by the parasite. In this experiment f mussels and five oysters were placed together in each of two glass vessels containing water salinity 28·3‰, at a temperature of 13° to 15° C. After four weeks all the molluscs were dissect In none of the oysters was the parasite found, but mussels in both vessels were infected. In o four out of five mussels contained a total of five parasites, in the other vessel, two out of f mussels contained sixteen parasites. All parasites were less than 3 mm.

These preliminary experiments suggest that Mytilicola does not easily invade oysters, and t conclusion was confirmed by other experiments made at Conway, in which oysters placed in ves of sea water, to which copepodids had been added, failed to become infected. Mussels trea by a similar technique almost invariably became infected.

Few oyster beds have so far been examined for parasites, but mussels from all the major oys producing areas in Britain are already infected. There is, therefore, the maximum chance of parasite becoming established in oysters if susceptible strains exist, or if the parasite should bec adapted in such a manner as to increase its chances of entering and surviving in oysters. *Mytil orientalis* (Mori) is already well established in *Ostrea gigas* in Japan (Mori, 1935) and on the Pac coast of the United States (Wilson, 1938), and in *Ostrea lurida* at Puget Sound, Washing (Odlaug, 1946). Odlaug concluded that the presence of the parasite adversely affected the condi of the host oysters. Further work is needed to show whether *Mytilicola intestinalis* is capable infecting oysters to a sufficient degree to bring about a loss of condition. Mussels in the vici of oyster beds form a risk to the oysters. This danger is not, as far as we know at present, great, but it may be wise to remove the mussels whenever this is practicable.

CONTROL

The possibility of using immune strains has been discussed by Dollfus (1951). It was succes for oysters in eastern Canada following an outbreak of contagious disease (Needler, 1941). Th is also the possibility that the incidence of Mytilicola may in time become adjusted in a de that is not deleterious, (*cf.* Korringa and Lambert, 1951). The indications at present, howe point to mussel culture as most hopeful, as adopted in France (Lambert, 1935) or the Netherla because Hockley (1951) found heavy infestation of mussels on flat beds at Plymouth, but parasites in mussels from the dock walls, and because of the observations reported in the pre paper. It must be admitted, though, that it may not always be advantageous to seek the lo rate of infection between tidemarks, because growth and fattening are best when the mussels fully submerged (Newcombe, 1935).

Apart from such a constructive reform as the wider use of cultural methods, there appear be a need for consideration of the best methods of reducing the spread of infection.

SUMMARY

1. *Mytilicola intestinalis* is recorded for the first time in mussels on the west coast of Engl and Wales at Barrow-in-Furness, in Milford Haven and along the coast of South Wales. It also found in mussels taken from the bottom of a tug scraped at Fleetwood, and plying betw

ow and Heysham. Evidence is adduced to show that transport of infested mussels on the m of ships, particularly those destined for breaking up, has been the chief means by which arasite has been distributed. Natural spread by means of the planktonic stages is slow, ey are of brief duration.

Mytilicola continues to breed while water temperatures exceed 6°C. Breeding is interrupted e average for about two months (February and March) on the east coast but usually continues ghout the year on the Channel coast, in the south-west and in South Wales.

In the Blyth estuary, Northumberland, the percentage infection and the average number of sites per infected mussel were lowest near the mouth and at a maximum in mid-estuary, being tly reduced again at the top of the estuary where the salinity at low water was much reduced. ne mouth of the estuary female Mytilicola were more abundant than males, in mid-estuary proportions of the sexes were about equal, at the top of the estuary males predominated. e tendencies were also evident in samples examined from other parts of the coast, but the rvations were insufficient to give firm conclusions.

Mussels exposed high on the shore were less heavily infected than those at low water mark. r factors believed to limit infection are turbulence and current speed.

Although oysters have been found to be lightly infected by Mytilicola in a few localities, riments with mixed mussels and oysters did not result in infection of the oysters, although mussels became parasitized. Copepodids hatched from egg-sacs removed from females d in oysters were successfully used to parasitize mussels.

Hatching of copepodids has been achieved at temperatures of from 6° to 19°C., with salinities om 17·2° to 30·8‰. Successful infection experiments have been made at salinities down 0·5‰.

ACKNOWLEDGMENTS

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TABLE 1

DISTRIBUTION OF SAMPLES AND PARTICULARS OF INFECTION—WEST AND SOUTH COASTS

ple).	Locality		Date	Average length of host cm.	Percentage infection	Heaviest infection	Total of parasites per 20 mussels	Average per infected host
	CUMBERLAND							
1	Ravenglass		20.2.51	5·63	0	—	—	—
2	Haverigg		20.2.51	4·95	0	—	—	—
	LANCASHIRE							
3	N. Walney Channel ..		22.2.51	5·17	10	1	2	1
4*	S. Walney Channel	(1)	30.3.51	5·85	0	—	—	—
5*	S. Walney Channel Outside Docks ..	(2)	28.3.51	5·68	15	1	3	1
6	Barrow-in-Furness ..	(1)	21.2.51	5·78	85	6	45	2·65
7	,, (Docks) ..	(2)	21.2.51	5·61	45	1	9	1·00
8	,, ,, ..	(3)	22.2.51	5·67	90	11	77	4·28
9	,, ,, ..	(4)	22.2.51	3·99	75	7	31	2·07
0	,, ,, ..	(5)	22.2.51	5·51	65	9	37	2·85
1	Roosebeck		6.2.51	5·60	0	—	—	—
2	Humphrey Head		16.2.51	5·26	0	—	—	—
3	Morecambe North		7.2.51	5·47	0	—	—	—
4	Heysham North		12.2.51	5·52	0	—	—	—
5	Heysham		13.2.51	5·24	0	—	—	—
6	Heysham Dock		13.2.51	5·10	0	—	—	—
7	Glasson Dock		6.2.51	4·77	0	—	—	—
8	Cockerham		13.2.51	5·55	0	—	—	—
9	Fleetwood	(1)	5.2.51	5·80	0	—	—	—
0	,, ...	(2)	27.2.51	5·58	0	—	—	—
1	,, ...	(3)	15.2.51	5·26	0	—	—	—
2	,, ...	(4)	6.2.51	3·42	65	14	79	6·08
3	,, ...	(5)	2.3.51	5·58	0	—	—	—
4	,, ...	(6)	8.3.51	6·53	0	—	—	—
5	,, ...	(7)	8.3.51	5·78	0	—	—	—
6	,, ...	(8)	15.2.51	5·29	0	—	—	—
7	Bar Lightship		21.7.51	2·83	0	—	—	—
8	Lytham		5.2.52	6·24	0	—	—	—
	CHESHIRE							
9	New Brighton		5.3.51	4·47	0	—	—	—
0	Wallasey		5.3.51	5·80	0	—	—	—
1	Dee Estuary		23.1.51	5·73	0	—	—	—
	CAERNARVON							
2	Conway		1.1.51	5·73	0	—	—	—
3	Menai Straits		7.1.51	5·73	0	—	—	—
4	Portmadoc		9.1.51	5·73	0	—	—	—
	ANGLESEY							
5	Holyhead		6.1.51	5·34	0	—	—	—
	MERIONETH							
6	Barmouth		11.1.51	5·73	0	—	—	—
7	Aberdovey		12.1.51	6·17	0	—	—	—
	PEMBROKE							
8*	Fishguard	(1)	4.6.51	5·80	0	—	—	—
9	,, ...	(2)	30.11.51	5·29	0	—	—	—
0	,, ...	(3)	30.11.51	5·72	0	—	—	—
1	Dale		5.12.51	5·17	10	1	2	1
2	Angle		12.11.51	5·00	6·25	1	1	1
3	Milford Haven ..	(1)	4.12.51	5·33	30	5	12	2
4	,, ,, ..	(2)	27.11.51	6·00	15	1	3	1
5	Pembroke Dock		27.11.51	6·28	85	12	67	3·94
6	Mill Bay		29.11.51	5·74	100	15	159	7·95
7	Pembroke Ferry		29.11.51	5·76	100	23	107	5·35
8	Neyland		29.11.51	5·88	100	31	87	4·35
9	Tenby		29.11.51	4·55	80	10	68	4·25

*Not personally collected.

TABLE 1 (*continued*)

Sample No.	*Locality*	*Date*	*Average length of host cm.*	*Percentage infection*	*Heaviest infection*	*Total of parasites per 20 mussels*	*Ave pe infe ho*
	CARMARTHEN						
50	Ferryside	2.1.52	4·80	100	26	217	10·
51	Llanelly	8.1.52	4·70	90	26	141	7·
	GLAMORGAN						
52*	Barry Dock	9.2.52	6·53	60	4	27	2·
53*	Sker Point	29.3.52	2·51	0	—	—	–
	DEVON						
54*	Appledore	8.2.52	6·47	0	—	—	–
	CORNWALL						
55*	Padstow	1.2.52	7·00	0	—	—	–
	SOUTH COAST						
57*	Poole	11.12.50	5·73	90	19	109	6·
58*	River Yealm	15.1.51	5·73	100	15	173	8·
59*	River Penryn	29.6.51	5·67	15	2	4	1·
60*	Lympstone	19.10.51	6·20	—	—	—	–

*Not personally collected.

ANALYSIS OF MUSSEL SAMPLES

(EACH COMPRISED 20 MUSSELS)

Sample No.	*Locality*	*Date*	*Males*	*Females with egg-sacs*	*Females without egg-sacs*	*Juveniles less than 3 mm.*	*Dam-aged*	*Total*	*Ratio ♂♂ : ♀♀*	*Hosts having only*			*Per cent infected hosts with 1 parasite*
										1♂	1♀	1 *Juvenile*	
	BARROW												
3	N. Walney Channel	22.2.51	—	—	2	—	—	2	—	—	2	—	100·0
5	S. Walney Channel	28.3.51	—	—	2	1	—	3	—	—	2	1	100·0
6	Barrow-in-Furness .. .. (1)	21.2.51	14	1	24	2	4	45	1 : 1·79	1	4	—	29·4
7	,, ,, ... (2)	21.2.51	3	—	4	2	—	9	1 : 1·33	3	4	2	100·0
8	,, ,, ... (3)	22.2.51	27	—	36	13	1	77	1 : 1·33	2	2	—	22·2
9	,, ,, ... (4)	22.2.51	12	—	13	5	1	31	1 : 1·08	2	3	—	33·3
10	,, ,, ... (5)	22.2.51	14	—	15	8	—	37	1 : 1·07	1	4	—	38·5
	Totals		70	1	96	31	6	204	1 : 1·39				
22	Fleetwood .. .. .. (4)	6.2.51	25	6	28	8	12	79	1 : 1·36	1	1	—	15·4
	PEMBROKE												
41	Dale	5.12.51	—	—	2	—	—	2	—	—	2	—	100·0
42	Angle	12.11.51	—	—	—	1	—	1	—	—	—	1	100·0
43	Milford Haven .. .. (1)	4.12.51	3	1	8	—	—	12	1 : 3·00	—	3	—	50·0
44	Milford Haven .. .. (2)	27.11.51	1	—	2	—	—	3	1 : 2·00	—	—	—	0·0
45	Pembroke Dock	27.11.51	27	14	13	8	5	67	1 : 1·00	1	2	—	17·6
46	Mill Bay	29.11.51	47	14	34	48	16	159	1 : 1·02	—	—	—	0·0
47	Pembroke Ferry	29.11.51	31	15	15	37	9	107	1 : 0·97	—	1	2	15·0
48	Neyland	29.11.51	19	7	21	34	6	87	1 : 1·47	4	3	—	35·0
	Totals		128	51	95	128	36	438	1 : 1·14				
	S. WALES												
49	Tenby	28.11.51	17	24	15	6	6	68	1 : 2·29	1	1	—	12·5
50	Ferryside	2.1.52	108	22	35	46	6	217	1 : 0·53	—	1	—	5·0
51	Llanelly	8.1.52	68	22	40	9	2	141	1 : 0·91	—	1	1	11·1
52	Barry Dock	8.2.52	—	2	11	11	3	27	—	1	3	—	33·3
	Totals		193	70	101	72	17	453	1 : 0·89				
	S. COAST												
57	Poole	11.12.50	36	23	15	27	8	109	1 : 1·06	—	2	—	11·1
58	R. Yealm	15.1.51	68	25	30	39	11	173	1 : 0·81	—	—	—	0·0
59	R. Penryn	29.6.51	0	1	2	0	1	4	—	—	2	—	66·6

TABLE 3

AVERAGE LENGTH OF PARASITES (in mm.)

Sample No.	*Locality*	*Date*	*Males*	*Females with egg-sacs*	*Females without egg-sacs*
	BARROW				
3	N. Walney Channel	22.2.51	—	—	7·75
5	S. Walney Channel	28.3.51	—	—	8·25
6	Barrow-in-Furness .. .. (1)	21.2.51	3·63	8·30	7·84
7	,, ,, ... (2)	21.2.51	4·33	—	7·10
8	,, ,, ... (3)	22.2.51	4·05	—	7·51
9	,, ,, ... (4)	22.2.51	3·70	—	7·10
10	,, ,, ... (5)	22.2.51	4·06	—	7·51
	MEAN LENGTH		3·95	8·30	7·58
22	Fleetwood .. .. (4)	6.2.51	3·82	7·57	6·6[illegible]
	PEMBROKE				
41	Dale	5.12.51	—	—	7·80
42	Angle	12.11.51	—	—	—
43	Milford Haven .. .. .. (1)	4.12.51	3·93	8·70	7·9[illegible]
44	Milford Haven .. .. .. (2)	27.11.51	4·01	—	7·1[illegible]
45	Pembroke Dock	27.11.51	4·00	7·75	6·3[illegible]
46	Mill Bay	29.11.51	3·85	7·41	6·36
47	Pembroke Ferry	29.11.51	3·92	8·14	6·11
48	Neyland	29.11.51	3·65	8·30	6·76
	MEAN LENGTH		3·89	8·06	6·92
	SOUTH WALES				
49	Tenby	28.11.51	4·26	7·68	7·74
50	Ferryside	2.1.52	3·72	7·62	6·6[illegible]
51	Llanelly	8.1.52	3·64	7·56	7·0[illegible]
52	Barry Dock	8.2.52	—	7·10	6·54
	MEAN LENGTH		3·87	7·49	6·99
	SOUTH COAST				
57	Poole	11.12.50	3·76	8·75	6·65
58	River Yealm	15.1.51	4·20	8·30	7·80
59	River Penryn	29.6.51	—	7·10	7·40

TABLE 4

SUMMARY OF PARTICULARS OF MUSSEL SAMPLES

Locality	*No. of samples*	*Percentage infection*	*Average No. of parasites per 20 mussels*	Percentage composition of parasite population				
				Males	*Females with egg-sacs*	*Females without egg-sacs*	*Juveniles (less than 3 mm.)*	*Damaged*
				per cent	*per cent*	*per cent*	*per cent*	*per cent*
Barrow	7	55·0	29·1	34·3	0·5	47·1	15·2	2·9
Fleetwood	1	65·0	79·0	31·6	7·6	35·5	10·1	15·2
Pembroke	8	63·5	54·8	29·2	11·6	21·7	29·2	8·2
South Wales	4	73·7	113·3	42·6	15·5	22·3	15·9	3·8

TABLE 5

BLYTH ESTUARY AND NEWBIGGIN

DISTRIBUTION OF SAMPLES AND PARTICULARS OF INFECTION

Sample No.	*Station No.*	*Station Description*	*Date*	*Average length of host*	*Percentage infection*	*Heaviest infection*	*Total of parasites per 20 mussels*	*Average per host*	*Position on shore or piles*
61	1	S. Harbour	30.4.52	4·55	50	2	11	0·55	Vertical
62		West Side of Jetty	,,	4·81	40	3	17	0·85	Horizontal
63			1.5.52	4·87	35	2	10	0·50	Uppermost
64		N. West Side of Jetty	,,	5·01	60	3	21	1·05	2 feet lower
65			7.5.52	5·38	80	6	39	1·95	5 feet lower
66			8.5.52	5·27	90	4	35	1·75	7 feet lower
67		N. East Side of Jetty	,,	4·95	15	4	6	0·30	Uppermost
68			,,	5·73	65	5	34	1·70	6 feet lower
69	2	Mid-Ferry N. Bank	10.5.52	5·37	80	6	51	2·55	V. Distribution 2′ only
70	3	High Ferry	16.5.52	4·55	80	8	52	2·60	Uppermost
71		,, ...	,,	5·28	85	24	123	6·15	6 feet lower
72	4	Tidal Basin Staiths	12.5.52	4·75	75	4	35	1·75	Uppermost
73		(Vertical Distribution)	,,	5·16	95	15	93	4·65	5 feet lower
74			,,	5·37	100	23	143	7·15	10 feet lower
75		Tidal Basin Flats	15.5.52	5·50	95	16	115	5·75	Horizontal
76	5	Cowpen Pool	14.5.52	5·20	100	12	93	4·65	Uppermost
77		(Horizontal distribution)	,,	5·86	90	12	95	4·75	3 feet lower
78	6	Sleekburn	15.5.52	4·96	80	8	65	3·25	Horizontal
79		,, ...	,,	5·17	85	11	66	3·30	4 feet lower
80		Newbiggin	5.5.52	5·61	100	15	143	7·15	Horizontal

DETAILED ANALYSIS OF MUSSEL SAMPLES (EACH COMPRISED 20 MUSSELS)

Locality	Date	Males	Females with egg-sacs	Females without egg-sacs	Juveniles less than 3 mm.	Damaged	Total	Ratio ♂♂ : ♀♀	Hosts having only 1 male	Hosts having only 1 female	Hosts having only 1 juvenile	Percentage infected hosts with 1 parasite
STATION 1												
S. Harbour	30.4.52	4	1	2	2	2	11	1 : 0·75	3	3	1	70·0
West Side of Jetty	,,	5	—	4	5	3	17	1 : 0·80	—	—	1	12·5
N. West Side of Jetty	1.5.52	4	—	4	1	1	10	1 : 1·00	—	2	1	42·9
,, ,, ,,	,,	5	3	11	1	1	21	1 : 2·80	2	3	—	41·7
,, ,, ,,	7.5.52	16	6	15	2	—	39	1 : 1·31	—	6	—	37·5
,, ,, ,,	8.5.52	19	2	12	2	—	35	1 : 0·74	4	2	—	33·3
N. East Side of Jetty	,,	4	—	2	—	—	6	1 : 0·50	1	1	—	66·6
,, ,, ,,	,,	14	6	12	1	1	34	1 : 1·29	1	1	—	15·4
Totals		71	18	62	14	8	173	1 : 1·13	11	18	3	36·8
STATION 2												
Mid Ferry N. Bank	10.5.52	20	8	18	5	—	51	1 : 1·30	1	2	—	18·7
STATION 3												
High Ferry	16.5.52	22	1	21	8	—	52	1 : 1·00	4	2	—	37·5
	,,	58	8	46	8	3	123	1 : 0·93	1	—	—	5·9
Totals		80	9	67	16	3	175	1 : 0·95	5	2	—	21·2
STATION 4												
Tidal Basin	12.5.52	9	3	19	2	2	35	1 : 2·44	2	2	—	26·7
	,,	49	7	28	8	1	93	1 : 0·71	1	2	—	15·8
	,,	66	8	45	18	6	143	1 : 0·80	—	—	2	10·0
	15.5.52	51	19	28	16	1	115	1 : 0·92	—	—	2	10·5
Totals		175	37	120	44	10	386	1 : 0·90	3	4	4	15·1
STATION 5												
Cowpen Pool	14.5.52	46	11	28	8	—	93	1 : 0·85	—	2	—	10·0
	,,	48	8	25	10	4	95	1 : 0·69	—	2	—	11·1
Totals		94	19	53	18	4	188	1 : 0·77	—	4	—	10·5
STATION 6												
Sleekburn	15.5.52	37	4	15	7	2	65	1 : 0·51	1	2	1	25·0
	,,	31	7	24	4	—	66	1 : 1·00	—	3	1	23·5
Totals		68	11	39	11	2	131	1 : 0·74	1	5	2	24·2

TABLE 7

AVERAGE LENGTH OF PARASITES AT BLYTH (in mm.)

Locality	*Date*	*Males*	*Females with egg-sacs*	*Femal witho egg-sa*
STATION 1				
S. Harbour	30.4.52	4·25	8·30	6·40
West Side of Jetty	,,	4·17	—	8·77
N. West Side of Jetty	1.5.52	3·77	—	7·20
,, ,, ...	,,	3·85	7·50	8·01
,, ,, ...	7.5.52	3·92	8·34	6·[illegible]
,, ,, ...	8.5.52	4·06	7·85	7·[illegible]
N. East Side of Jetty	,,	4·50	—	8·[illegible]
,, ,, ...	,,	4·17	8·88	7·[illegible]
MEAN LENGTH		4·09	8·17	7·[illegible]
STATION 2				
Mid Ferry N. Bank	10.5.52	3·94	8·20	7·43
STATION 3				
High Ferry	16.5.52	3·86	7·70	6·2[illegible]
	,,	3·85	8·58	6·[illegible]
MEAN LENGTH		3·85	8·14	6·[illegible]
STATION 4				
Tidal Basin..	12.5.52	3·85	8·60	6·[illegible]
	,,	3·88	8·01	6·[illegible]
	,,	3·87	8·38	7·[illegible]
	15.5.52	4·48	9·19	7·6[illegible]
MEAN LENGTH		4·02	8·54	6·9[illegible]
STATION 5				
Cowpen Pool	14.5.52	4·10	7·97	7·2[illegible]
	,,	4·33	9·00	7·5[illegible]
MEAN LENGTH		4·22	8·48	7·4[illegible]
STATION 6				
Sleekburn	15.5.52	3·84	7·07	6·8[illegible]
	,,	3·92	8·09	6·9[illegible]
MEAN LENGTH		3·88	7·58	6·8[illegible]

TABLE 8

BLYTH ESTUARY

SUMMARY OF PARTICULARS OF MUSSEL SAMPLES

Station	*No. of samples*	*Percentage infection*	*Average No. of parasites per 20 mussels*	*Males*	*Females with egg-sacs*	*Females without egg-sacs*	*Juveniles (less than 3 mm.)*	*Damaged*
				per cent	*per cent*	*per cent*	*per cent*	*per cent*
1	8	54·37	21·62	41·1	10·4	35·8	8·1	4·6
2	1	80·00	51·00	39·2	15·7	35·3	9·8	—
3	2	82·50	87·50	45·7	5·1	38·3	9·2	1·7
4	4	91·25	96·50	45·3	9·6	31·1	11·4	2·6
5	2	95·00	94·00	50·0	10·1	28·2	9·6	2·1
6	2	82·50	65·50	51·9	8·4	29·8	8·4	1·5

APPENDIX

NOTES ON METHOD OF DISSECTING OUT THE GUT OF MYTILUS

1. The left valve is first removed. This is done by holding the mussel in the left hand, the left valve uppermost and the dorsal side of the animal away from you. Next, the valves pushed in opposite directions along the axis of the body ; the left valve away from, the right v (the underneath one) towards you. A strong scalpel is introduced on the dorsal side of the valve at a point just anterior to the main adductor muscle. The scalpel, with the edge against the left valve, is drawn towards the posterior margin of the shell and then backw around the perimeter of the valve to free the edge of the mantle on the ventral side. The sc is then withdrawn and passed forward, from the point of insertion to the umbo. The left v is now twisted off. It may, however, be found necessary to probe with the scalpel blade ag the inside of the left valve to detach a "sticky" piece of mantle or to sever the anterior addu and byssal retractor muscles. The secret of opening a mussel cleanly is to ensure that the sc is always held closely against the upper (left) valve.

2. *Removing mantle and gills.* The right valve is placed on a folded duster under a disse lens. The edge of the right mantle is detached from the right valve. This is best done by i ducing the joined tips of a pair of fine tweezers just in front of the exhalant aperture and, keeping them close to the right valve, running them anti-clockwise as far as the mouth. holding the left mantle just below the exhalant opening, lift it upwards and forwards. It w found that after a little practice the mantle and gills of the left side come away together. W however, the gills are left, they can be removed cleanly by taking them in the tips of the tw at a point which is level with the bottom of the posterior adductor muscle and just in fron Held like this, they are easily torn off.

3. *Remove the palps.* This is a most important step towards the later removal, without br of the loop of the gut. The removal of the palps allows the loop to slip over the oesopha

4. With the back of a small scalpel, scrape away the digestive gland very carefully, beg immediately in front of the heart. This can be made easier by pushing up the digestive from underneath with the first finger of the left hand placed in the valve. Follow out eac of the recurrent intestine until the whole loop is uncovered.

5. Make an incision, commencing at a point below the junction of the direct and rec intestines with the digestive gland, passing beneath and parallel to the crystalline styl and the first part of the recurrent intestine, which here lie side by side. Continue this in back so as to free the rectum from the posterior adductor muscle.

6. With tweezers, take hold of the three thicknesses of rectum and direct and recurrent inte just in front of the posterior adductor muscle and pull very gently upwards and forwards. little difficulty is normally encountered in removing the gut intact from the point where it the stomach to the anus. Place the gut in a watch glass of sea water.

7. Detach the digestive gland and contained stomach by lifting it out upwards and for with the tweezers and place in another watch glass of sea water.

8. The gut is then opened out, along its entire length and the contents removed.

9. The stomach and the main ducts of the digestive gland are opened.

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